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Lighting Developments in Czechoslovakia

By JIRI HAVELKA, B.E., B.Sc.

Summary

The paper gives an account of research work carried out in Czechoslovakia in the last 10 years. The problem of the economical rated voltage of incandescent lamps is analysed in general and the economical voltage derived for cases of varying mains voltage and cost of electrical energy. The attainable economy is critically evaluated.

The second part of the paper deals with the economical interval for maintenance and re-lamping and the method of its computation. Special attention has been paid to the investigation of the most favourable arrangement of fluorescent tubes for factory lighting and an attempt made to express the quality of illumination by a single "quality index" to enable a clear comparison of the individual arrangements.

A new type of fluorescent lantern for street lighting at low temperatures is described.

(1) Historical

Before World War II Czechoslovakia had a well-developed industry which produced diffusing glassware for fittings in a large variety of shapes and designs. That was perhaps the main reason why the C.I.E. Secretariat on Diffusing Materials was assigned to Czechoslovakia for several years. During the war and the German occupation of the country, this special section of the glass industry practically ceased to exist and thus, obviously, also the participation of Czechoslovakia in international co-operation. After the war, reconstruction and then a large-scale new building for industry began throughout the whole country. Closely associated with this was the construction of new power stations, but the demand for electrical power always exceeded the building possibilities. At the same time the electric grid was extended, especially for the purpose of rural electrification which in the last five years has reached 90 per cent. of all farming localities. The demand for power supply was so great that the Electricity Board was obliged, in the winters of 1952 to 1954, to cut supplies and to enforce strict economy in all consuming sectors. It is not surprising that under such circumstances special attention was paid to lighting, which accounted for 18 per cent. of the total electricity generated.

The main task of the research in Czechoslovak illuminating engineering was, therefore, to discover every possible means of saving power on the assumption that only light sources made by our own industry could be used. This limitation complicated the whole matter and, because of great urgency, the problem had to be tackled from different angles.

The following items were considered to offer the best possibilities of effecting economy:—

(1) The use of the most economically rated voltage of incandescent lamps.
(2) To ascertain the appropriate sort and interval of maintenance (including re-lamping, cleaning and painting of walls and ceiling).
(3) To replace, in factories, incandescent lamps by fluorescent tubes and to find out their best geometrical arrangement.
(4) To divide the wiring system into suitable sections and to introduce auxiliary lighting for passages and gangways.
(5) To use fluorescent tubes for street lighting even at low temperatures.

Experiments were carried out in more than 70 large establishments with the willing co-operation of many workers and members of technical staffs. Thousands of

The author is with the National Lighting Laboratories in Czechoslovakia. The paper was presented at the Society's Summer Meeting at Harrogate on May 10, 1956.

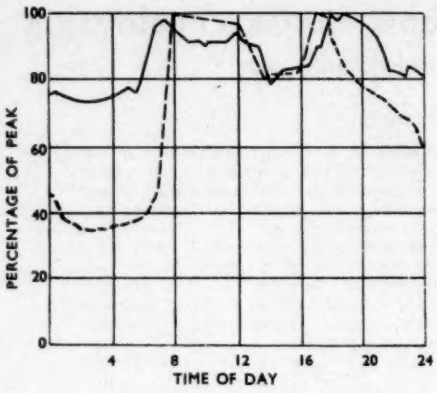

Fig. 1. Power supply graphs (20 January, 1955)

——— *Czechoslovakia*

- - - - - - - - - - - - *Britain*

measurements were made and the results obtained have been carefully examined on a strictly mathematical basis, to avoid every possibility of optimistic conclusions. The results, which will be mentioned later, are in many respects surprising.

During 1955, the balance between power demand and supply in Czechoslovakia was re-established by the commissioning of new generating plants (especially large hydro-electric stations for peak loads), by the general introduction of the three-shift system in industry and by restrictions of domestic current consumption by imposing prohibitive rates for extravagant consumers. A clear picture of the present situation in power supply will be seen from the diagram comparing power generation in Great Britain and Czechoslovakia (Fig. 1).

The power supply for factories and large consumers is planned in advance not only in terms of total quantity, but also in consumption per hour of the working day. These mutually agreed limits are controlled by special State power supply inspection officers and every infringement is followed by a substantial increase in rates. These limitations were very irksome but were, on the other hand, so successful that since the spring of 1955 no current cuts have had to be imposed anywhere in our country.

(2) Economical Voltage of Incandescent Lamps

The problem of ascertaining the optimum voltage has been often referred to in the literature. It was, therefore, decided thoroughly to deal with it once more on a large scale experimental basis, followed by mathematical analysis[1].

It is common knowledge that, with variation of the rated voltage, the light output of an incandescent lamp varies as nearly the fourth power and the average life as the fourteenth power. For further consideration, it was necessary to define the term "cost of light" and the megalumen-hour (Mlmh) was chosen as the unit of light quantity. The cost of producing that amount of light consists of the total cost of the electrical energy consumed together with the cost of the light source. The total cost of producing one megalumen-hour of light can be expressed by the formula :—

$$E = \frac{10^3}{F_o}\left(\frac{Z}{T_o} \quad 10^3 + WN.\right)$$

where : E = cost of one megalumen-hour of light in shillings.

F_o = rated light output in lumens, i.e., the mean light output throughout the average life of the lamp.

Z = cost of the lamp in shillings. (This includes not only the purchase tax, but also all other expenses, such as the storage of lamps, re-lamping, maintenance and other items including all the overhead expenditure.)

T = life of the lamp in hours.

W = price per kilowatt-hour in shillings. (Should a progressive tariff, with fixed basic charges, be applied all price variations must be taken into account.)

N = consumption of the lamp in watts, i.e., the mean value for the whole life of the lamp.

This formula expresses both components from a purely financial point of view. As long as it is regarded as more important to save energy, even at higher general cost, or if again it is more important to save lamps, it is possible to express this tendency in the basic formula by special "loading factors" which are added to the cost of current or of the lamps respectively.

It is obvious that, with increase of lamp voltage, the light output and current consumption also increase and the life of the lamp is greatly reduced. With low current rates, the decisive factor will be, therefore, the price of the lamp, but with higher current rates this factor loses its importance and the cost of electrical energy becomes the decisive factor. Between those two extreme instances, the optimum cost could be found, by simple mathematical calculation, if every change in lamp quality is expressed as an exponential function of voltage.

Figures 2 to 5 show groups of curves which represent the cost of light in pounds sterling per megalumen-hour for lamps in general use and for different costs of electrical energy. It is interesting to observe the "cost of light" for a megalumen-hour of light produced by a 15-watt lamp. If the rated voltage is applied to this lamp, the cost would be something about £14, but if the optimum economical voltage is applied, (0.79 of the rated value) the cost would be reduced to only £5, which represents an important saving indeed.

Figure 3 shows curves for cost of energy at 1d. per kilowatt-hour. It can be seen that the optimum value is close to the rated voltage especially with lamps of the higher wattage ratings, but with lamps of 15, 25 and 40 watts there is still a big opportunity for economy. If the cost of power were increased to 4d. per kilowatt-hour the optimum voltage of the 1,000-watt lamp would just equal the rated one.

The group of curves in Fig. 5 corresponds to cost of power at 1s. per kilowatt-hour, which is our existing power rate for private consumers and rural establishments. The optimum voltage for a 1,000-watt lamp is above the rated one; in this case current economy overweighs even the relatively high price of the lamps. That is important, especially for street-lighting, where 1,000-watt lamps are sometimes used.

Table 1 gives a general survey of optimum voltages for lamps of different ratings and for various costs of power. It is a rather surprising fact that the range of both extreme voltages extends from 200 to 275 volts.

For large factories using thousands of lamps and with a special maintenance shop, it is no trouble to keep in stock only lamps of economic voltage ratings. Those lamps, moreover, can be purchased at normal prices.

The economy which could be achieved in the whole industry of our country has been evaluated, taking into account the average cost of power supplied and the percentage of lamps of different ratings of the total numbers applied, and it was found that the saving obtainable in expenditure on lighting in the whole of Czechoslovakia could amount to 6.5 per cent., representing about £2,000,000 per year. It should perhaps be mentioned here that cost of energy in Britain is at present lower than in our country and, therefore, an even greater economy might be achieved.

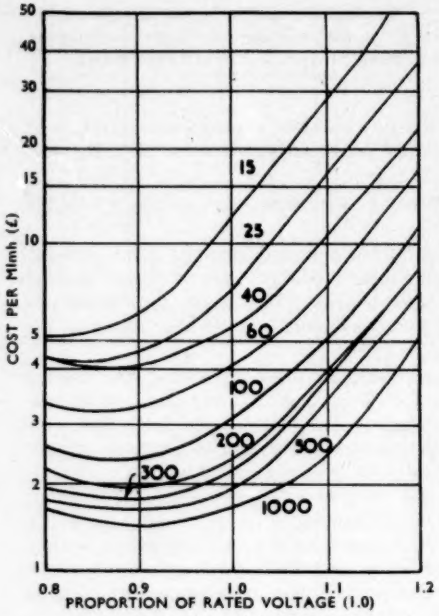

Fig. 2. Current at 3/4d. per kwh.

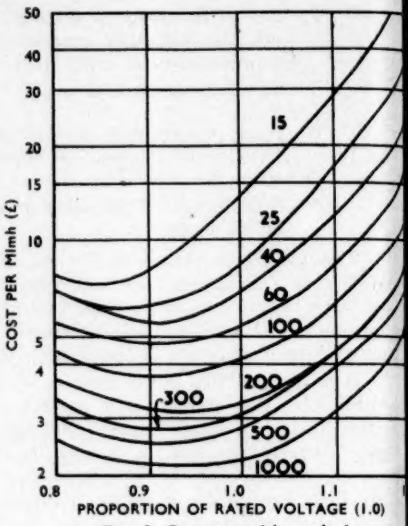

Fig. 3. Current at 1d. per kwh.

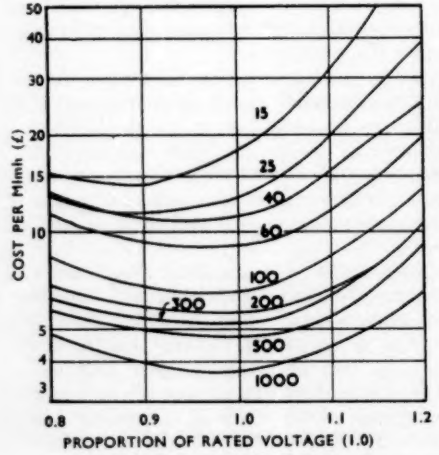

Fig. 4. Current at 4d. per kwh.

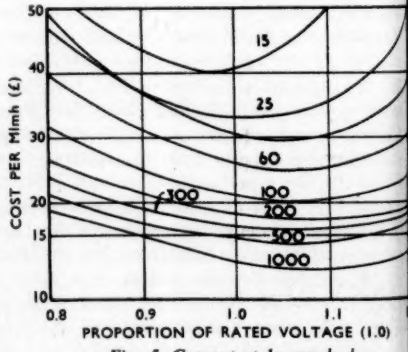

Fig. 5. Current at 1s. per kwh.

Table 1
Optimum voltages for lamps of different ratings at varying costs of current

Rating (watts)	1d.	1.5d.	2d.	3d.	4d.	6d.	1s.
15	275.5	268.2	260.4	252.8	244.4	238.4	224.3
25	264.6	258.2	250.6	244.4	236.6	231.5	215.2
40	254.4	247.5	238.7	233.2	225.4	220.2	206.4
60	252.8	246.2	237.7	232.0	224.7	219.0	205.7
100	248.7	242.7	234.5	228.9	221.5	216.7	203.4
200	248.4	241.9	233.8	228.0	221.0	215.6	203.1
300	250.8	244.2	236.3	230.5	223.2	218.2	205.1
500	250.0	243.2	235.4	230.0	222.8	217.7	204.8
1,000	244.8	238.6	231.6	226.4	219.7	214.5	200.2

The use of optimum voltage has other advantages, in addition to financial economy —especially in factories. The lamps operating at economical voltages have underheated filaments and have, therefore, a very long life. They are also more resistant to mechanical shocks and, under this condition, normal lamps can be eventually used instead of special shock-proof lamps.

With the aid of some more complex equations it is possible to find the optimum economical voltage for lamps used for two different power tariffs in different time periods. The calculated optimum voltage has to be, in most cases, slightly corrected according to voltages normally manufactured. In Czechoslovakia lamps for 210, 220, 225, 230, 240, 250 volts are produced as normal ratings. Due to the experiments described above it has now been proposed to add 270 volts for 15- and 25-watt lamps. The actual difference in economy between the lamps for exactly calculated voltages (which are not in production) and the slightly corrected voltages is practically negligible.

(3) The Appropriate Maintenance Interval

Loss of light flux observed with different fittings can be caused either by dust deposition, or by deterioration of reflecting surfaces. Of these two phenomena the dust deposition is far the more important. To obtain practical results, it was necessary to investigate different kinds of dust, especially in industrial workshops, and the speed with which the particles are deposited. The largest deposits have been observed on horizontal surfaces and on all areas exposed to turbulent air flow. The vertical parts and all surfaces exposed to laminar air flow showed relatively thin deposits because the dust particles move along the surface. More thorough knowledge of air flow round the fitting will surely influence design in the future. For further experiments a great number of different factories, workshops, offices and drawing offices have been kept under observation and the progress of dust deposition checked by repeated light measurements under the same conditions. The regular time interval for these measurements was a month and the experiments were carried out over a period of nearly two years(2).

The total light losses during six months are plotted in a group of curves in Fig. 6. Curve 1 represents the light losses in a drawing office of a large factory with double windows, central heating and fluorescent lighting; maximum illumination was about 30 lm/ft^2. Curve 2 is for an office in a suburban district of a large city. The room had simple windows, hot water heating and was illuminated by three semi-direct light-

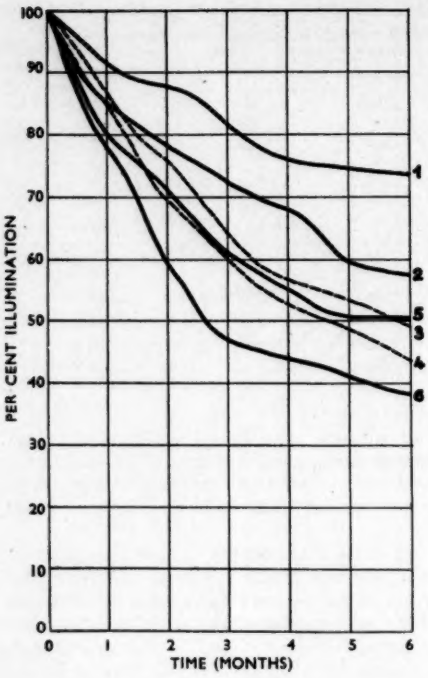

Fig. 6.

ing fittings with 200-watt lamps; maximum lighting intensity was about 11 lm/ft². Curve 3 illustrates a store house with closed glass brick windows. Four white enamelled fittings on the ceiling with 500-watt lamps were used; maximum illumination was 10 lm/ft². Curve 4 represents a mechanical workshop equipped with lathes, drills and grinding machines; the shop was steam heated and ventilated by an electric fan. Simple direct lighting fittings with white enamelled reflectors and 500-watt lamps were used; maximum illumination was 6 lm/ft². Curve 5 shows a precision workshop equipped with small lathes, grinding and polishing machines. It was provided with double windows in steel frames, central hot water heating and was lit by seven fittings, each containing three fluorescent 40-watt tubes; maximum illumination was 20 lm/ft². Curve 6 illustrates a hardening workshop with four furnaces and six hardening furnaces. The room was full of smoke and dust. It was steam heated and ventilated by an electric fan; five white enamelled direct lighting fittings with 1,000-watt lamps were used and the maximum illumination was about 20 lm/ft². These practical experiments have been followed by laboratory research with dusts of different particle sizes and consistency and at different temperatures. The laboratory tests showed good agreement with practical findings.

The verification of actual maintenance costs was carried out in nearly 50 different factories. After some statistical evaluation it has been found that the maintenance cost varied from 10d. to 2s. 6d. for one cleaning, although in some instances it reached nearly 4s. The main reason was the inaccessibility of the fittings, which were sometimes suspended at a height of more than 30 ft. Double ladders of this height are clumsy and difficult to handle. In larger workshops equipped with cranes a special

"maintenance platform" may be used, but in the three shift operation system this maintenance interrupts the normal operation of the crane.

Re-lamping is sometimes carried out with special clipping rods, but these rods can be used only for open fittings at limited heights. The replacement of lamps can be carried out individually when only the burnt out lamp is replaced, or, without regard to the actual lamp condition, in groups. This group replacement can be carried out either after 60 per cent. of the rated lamp life when, according to the law of probability, 6 per cent. of the total number is burnt out, or after 80 per cent. of the rated lamp life, when the quantity of burnt out lamps would reach 16 per cent. In any case, it is always advantageous to combine re-lamping with cleaning.

The reflection of light from the walls and ceiling is also reduced by dust deposition to approximately one half of its initial value in three to six months. These losses could be of some importance only when indirect lighting fittings are used.

The computation of the economical time period for cleaning is rather complicated and could be carried out only step by step. Fig. 7 shows a graphical method of calculation. The average expenditure for maintenance in relation to time period in logarithmic terms is represented by the straight line C. The cost of losses caused by dust deposits is represented by the curves W_1, W_3 and W_{10}. It is evident that the amount of wasted power depends on the time of use and the indices 1, 3 and 10 symbolise the time of use per day. When adding up expenditure for maintenance work and wasted power, the resulting curves S_1, S_3 and S_{10} are obtained, representing the total expenditure for every interval of use with clearly defined minima.

From these observations it can be concluded that the maintenance period should be reduced with rising cost of power, with increasing power consumption of light sources, with longer intervals of their use, with the amount of dust in the ambient atmosphere and, to a certain extent, even with the temperature of the room. On the other hand, when the maintenance work is very complicated and needs perhaps special arrangements, longer periods between maintenance times are more economical.

The saving thus achieved was evaluated in a large number of different factories. As a typical example, a medium size machine shop with 750 workers and 836 lighting fittings, equipped partly with incandescent lamps, partly with fluorescent tubes, may be mentioned. The original maintenance period was six weeks for drawing offices, offices and clean laboratories; three months for clean workshops and store rooms, and

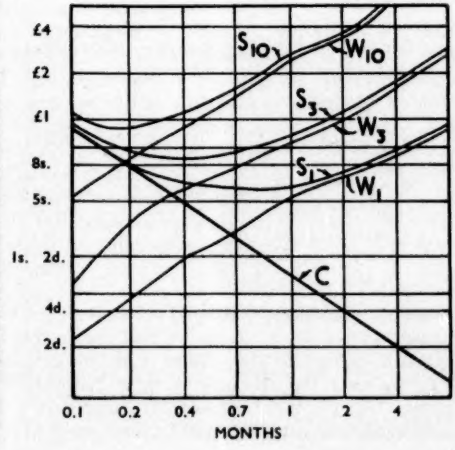

Fig. 7.

four months for dusty workshops. The total expenditure, including maintenance cost and power losses was £7,437 per month. After the introduction of a new economical maintenance period the total expenditure was reduced to only £949, i.e., to something less than one seventh of the original sum. This economy was achieved simply by better organisation. This example shows also that in comparatively clean rooms the maintenance period is shorter than in those with unfavourable conditions.

Other aspects of the research have been very useful for fittings designers. Special attention is now given to the accessibility of all parts for maintenance purposes and designers are getting accustomed to proving the practical value of their design not only on the drawing board, but also on the ladder with screwdriver and pliers in hand.

(4) The Most Favourable Arrangement of Fluorescent Tubes for Factory Lighting

The most favourable arrangement of fluorescent tube fittings in large rooms is very important especially for precision work factories where good lighting should be combined with saving in operational cost. The research laboratory had in recent years a very good opportunity to study this question systematically in large rooms measuring 36 × 50 ft. Two types of commonly used fittings have been tested and iso-foot-candle curves worked out[3].

The whole system of lighting fittings was fixed to a grid suspended on steel ropes, which could be raised or lowered as a whole. The average height over the floor could be changed from 3 to 14 ft. and the arrangement also allowed adjustments to be made to meet special requirements. Contrary to common practice, the illumination was measured directly on the floor to enable the iso-foot-candle curves to be plotted directly on the floor in chalk.

For the numerical evaluation of different arrangements of the fittings it was necessary to find out all decisive factors which might influence the quality of the lighting. The following were chosen as characteristic factors:—

s = area in square feet served by one fitting.
E_x = maximum illumination (lm/ft²).
E_n = minimum illumination (lm/ft²).
E_s = mean illumination (lm/ft²).
ϵ = uniformity of illumination.
g_s = mean illumination gradient.
g_x = maximum relative illumination gradient.
μ = quality index.

The relative importance of all those factors has been expressed by the formula:—

$$\mu = s \quad E_s \sqrt[5]{\frac{\epsilon}{g_x}}$$

After numerical evaluation, the final quality of the arrangement might be represented by a single figure.

The lighting arrangements (see Fig. 8) were evaluated as follows:—

(1) Simple uninterrupted rows — Quality index 3500
(2) Regularly interrupted rows — Quality index 1700
(3) Alternately interrupted rows — Quality index 2400
(4) Grid of interrupted squares — Quality index 2000

It is impossible to refer to every detail of several thousands of measurements, but even this brief information is in some respect instructive. It shows that the system of simple uninterrupted rows is of far superior quality to the others. One of its main advantages is the uniformity of the lighting over the whole area, provided that the distance between the adjacent rows is not too great. The second place, as far as quality is concerned, belongs to the arrangements with alternately interrupted rows.

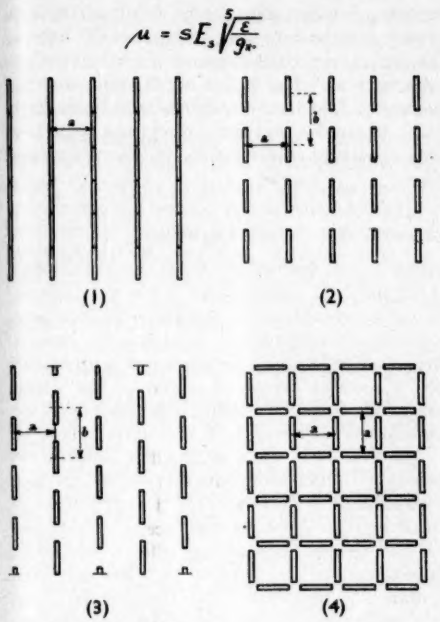

Fig. 8.
(1) Simple uninterrupted rows
(2) Regularly interrupted rows
(3) Alternately interrupted rows
(4) Grid of interrupted squares

A little surprising is the relatively low quality index of the square grid system where better results were expected.

The designer of the lighting system is sometimes interested in the shape of the shadows in the room. All "line" systems develop linear shadows, which could eventually upset some kinds of precision mechanical adjustment. With this special requirement in mind, it would be better to use the square grid arrangement. The reflection from white-washed walls has a favourable effect on all four kinds of the above-mentioned arrangements.

A problem very often discussed is the stroboscopic effect of fluorescent tubes, especially for mechanical workshops with lathes, milling machines, drills and grinders. Careful investigation proved that none of the four fittings arrangements referred to has any special advantage in this respect. It is therefore evident that the stroboscopic effect can be suppressed only with the longer afterglow of the luminescent material or by dividing the fluorescent tubes used in the room into appropriate sections, connected to all three phases of the supply. The most efficient method is to use fluorescent tubes with different phases in each fitting.

These conclusions are, of course, valid only for one sort of fitting, but as long as there is no substantial change in design and light flux, they would apply to other cases as well.

(5) The Introduction of Auxiliary Lighting

The lighting in modern establishments is based mostly on the use of fluorescent tubes. In addition to the normal working shift, when the lamps are burning for several hours, there are many other occasions when the lighting is needed only for orientation purposes and the illumination could be substantially reduced. It has been proposed

to use auxiliary lighting for this purpose, using incandescent lamps fixed on the tops of some fluorescent tube-fittings. To avoid unnecessary use of the main lighting the switch for the auxiliary circuit was placed close to the door at a normal height, where everybody is accustomed to switch the light on. The switch for the main lighting system is in an unusual place, 2 ft. above the floor, so that one must bend to reach it. The system of auxiliary lighting is now a common practice in all new electrical installations and results not only in economy of energy consumption, but in an increase in the average life of the fluorescent tubes.

(6) New Fluorescent Lanterns for Street Lighting

During the last two years, the production of fluorescent tubes has developed, some attempt has been made to use this economical light source for street lighting. The meteorological conditions in Czechoslovakia are not too favourable and in winter-time the temperature drops to -5 deg. F, and sometimes even to -10 deg. F. Normal fluorescent tubes, which were available, were unable to start at such a low temperature and it was, therefore, necessary to develop a suitable design of lantern. The design was prepared for two or three 40-watt fluorescent tubes. A simple light metal frame, housing chokes, starters and wiring terminals is covered with a curved sheet of synthetic acrylic plastic material. In the middle is a white enamelled reflector of triangular cross-section. The plastic cover has a rubber joint which is slightly pressed into the groove in the frame and has an advantage in needing only a slight pressure for fitting and compensating for inequalities in the frame. Experiments carried out in a large electric refrigerator proved that the temperature in the lantern was some 45 deg. F. higher than outside. The heat produced by the fluorescent tubes and their auxiliary equipment was sufficient to maintain the temperature at the normal level, necessary for efficient light output. Only in exceptional cases was it necessary to put a small heating lamp of 25 watts inside the lantern to maintain the temperature in hard frosts.

We also tried-out in practice some ideas for easy maintenance. The plastic bowl can be opened by unscrewing four butterfly nuts and is held in a half open position by steel ropes. All maintenance work can be carried out by one person without any instruments and every part of the lantern is easily accessible.

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Discussion

MR. A. G. PENNY: Mr. Havelka's analysis of the determination of the cheapest method of obtaining light is very interesting. Similar investigations have been made in many countries, and the reasons for carrying them out have varied in different countries. I think, however, that it is desirable to go back to fundamental considerations before attempting these investigations. Almost everywhere in the world to-day, there is a shortage of power, and civilisation advances only to the extent to which man can make use of power. Then he can use machines to free himself from repetitive work and afford him an opportunity to indulge in creative effort.

We know, to-day, how much light we require for any particular task; I think we

should bend our efforts to getting this light for the lowest possible consumption of energy. If we make lamps, for instance, to last 2,000 instead of 1,000 hours, we shall use half as many lamps but 10 per cent. more energy. So far as I know, the cost of producing this extra energy in terms of manpower is, in every part of the world to-day, much greater than the saving in lamp manufacture.

Even on this basis there are, however, other factors which have to be considered. For instance, lamps of a very short life, say 500 hours, are a nuisance because manpower is needed to change them, so any calculation suggesting that 300 hours is an economic life would, for normal lighting purposes, be unattractive. (For special purposes, of course, as for a projector, lives of only 25 hours can be an economic proposition.) At the other extreme even the best filament lamps are relatively fragile and there is always a risk, a certainty I think, that eventually a lamp will be broken if left burning long enough. However we design the lamps it will come to an end for some reason over which we have no control. I would therefore suggest that the region over which economic calculations, such as Mr. Havelka has described, can be allowed to play their part is somewhere between 500 and 2,000 hours.

As Mr. Havelka said, the consumer can determine by suitable calculations what kind of lamp can be used for what particular circumstance. We in Britain are fortunate in that lamps are relatively cheap and are tending to get cheaper; power, however, tends to get more expensive. Therefore, the British market is best served by relatively shortlived, highly efficient lamps. In other countries, where mechanisation is not so advanced and where there is an adequate water supply to produce cheap power, the situation is reversed. In those countries where there is a shortage of light sources and electrical energy, there may be some justification for a system of rationing by taxation on both lamps and power, and for the rationing being adjusted from time to time to suit the prevailing availability of the two components. British Governments have used purchase tax for similar purposes, but I cannot say I am convinced that this is a good system.

For exporting countries such as ourselves it is, of course, important that there should be some international agreement as to what should be done, and we should note that this situation is being studied internationally. The International Electro-Technical Commission which is now preparing international specifications for lamps has decided, after surveying all conditions, that it is best for lamps to be designed to have a nominal average life of around 1,000 hours so that consumers, with the aid of the sort of calculations Mr. Havelka has made, can make the appropriate adjustments locally.

Whether or not consumers can, in fact, make the correct adjustment is, I think, sometimes open to doubt. In Mr. Havelka's case, as he showed you, the load factor is very even so that the voltage variations are not very great. As I think Mr. Kemp mentioned yesterday, in England volt drops of 15 per cent. occur and I am sure members of the audience can quote cases where plus 15 per cent. occurs quite unpredictably. In these circumstances I think it is doubtful whether it is worthwhile trying to make these evaluations. Certainly I do not imagine people in this country would feel it was a good idea to change lamps as the volts go up and down. As Mr. Havelka showed, the curves relating these factors are relatively flat and you can spend a lot of time making investigations and changes, but the net result will not be significant.

On maintenance, Mr. Havelka described some studies in air flow in and around the fittings, and I think that is a very important matter. Much is being done in this country and a better understanding of these matters will, I think, lead to improved lighting performances in practice. I am interested to hear that he also has the situation we have over here, where the dirtiest places are cleaned less frequently

than the cleaner ones. That I suppose is due to human nature; after all the dirtiest boys are the least willing to go to the bathroom.

Mr. Havelka did not mention, in his calculations of lighting quality, whether he had made any allowance for the general appearance of a lighted room. I can imagine—in fact, I know of—cases in this country, where the workers have complained if there is the odd light out here or there. It may not have a significant effect on the average illumination, but people rightly tend to get very critical of appearance.

I was also interested to see that the algebraical formula trying to equate the intrinsic quality of various lighting systems gave the highest marks to continuous lines of fittings. I note Mr. Havelka was somewhat surprised that the square formation did not give a better result. I think my immediate reaction would be to consider whether, if common sense suggests that the answer is wrong, the error lies in the original formula.

Mr. Havelka referred to switches to which you have to stoop to operate. I have a strong suspicion that, in this country, low-mounted switches would soon become foot operated!

MR. J. M. WALDRAM: Mr. Havelka calculated the cost which results from the soiling of lighting fittings for which there were two items of cost: the carrying out of maintenance and the cost of the power which was wasted. This argument seems to me to contain a fallacy. The cost of lighting consists of the extent to which you have to put your hand in your pocket; firstly, to pay the maintenance man, and secondly, to pay for power. If I consume a certain load and my fittings get dirty it does not affect the amount of power I consume and its cost, and I wonder, therefore, whether we are correct in assessing that power as having been wasted and having to be paid for, because we have to pay for it anyway. I do not think that argument is correct unless you can and do switch on more lights in order to make up for the illumination you otherwise would not have—a procedure which is very seldom carried out.

One might equally well consider a number of other losses that take place in the lighting fitting, even when it is clean, and work out the cost of light which does not get on to the job.

In thinking of the life of our lamps, we have always thought in terms of total burning hours. That is, of course, of considerable general interest, but the interest of the user is not the number of burning hours, it is the installation life of a lamp. To the user, especially the domestic user, the biggest factor is how often he needs to put in a new lamp, especially if he has not got one. The installation life of lamps naturally depends upon the burning hours employed in the building; for example, Professor Schneider referred to schools, where the installation life of lamps is very great. That, I think, is probably of no less importance than the actual burning hours, because it tallies with the frequency of maintenance, which is based not on the burning hours but on the elapsed time.

I was very interested in the figures Mr. Havelka gave which relate to the uniformity of life achieved in the lamps he uses. We have heard a lot about the life of lamps, but we are not usually given data of the variation in their life. That, I think, is at least as important as their total life. He mentioned that if lamps are removed at 60 per cent. of their nominal life, about 6 per cent. of the lamps fail before removal: if you wait until 80 per cent. of the nominal life of the lamps, about 18 per cent. of the total lamps fail before removal. In this question of group replacement of lamps, and particularly when we are concerned with the lamps of very much longer life than

tungsten filament lamps, the uniformity of life is of no less importance than the total length of life.

MR. H. F. STEPHENSON: With regard to the depreciation curves shown on the slides, the amount of light lost, particularly on curve No. 6, is much greater than we have measured in this country even for very dirty industrial situations. Do these curves include the normal fall-off in lamp light output as well as loss of light due to dirt on the fitting?

If so, I would be interested to know whether the author has made any depreciation tests in which the separate components have been measured, i.e., the loss due to dirt on the lamp, that on the reflector and the actual lamp depreciation during the test.

I would also like to know whether he has made comparative trials in his country of closed top and through draught fittings. I have found that through draught fittings keep much cleaner; for example, in a foundry over a period of ten months the overall loss in light output was only 20-25 per cent. compared with 30 per cent. for a closed top fitting. These figures are much less than the loss of 70 per cent. which I think one of the curves indicated.

Finally, in trials with fittings equipped with H.P.M.V. and filament lamps it is found that the amount of dirt collecting on the H.P.M.V. bulb is much less than that on the filament lamp. This seems to be due to the fact that the vertical sides of the H.P.M.V. tubular bulb collect less dirt than the rounded upper part of the filament lamp bulb.

MR. C. J. KING: Details were given in the paper of recommended tungsten lamp voltages to ensure economical working under the conditions laid down by Mr. Havelka. I did not note any reference to the nominal supply voltage on which these lamps were expected to operate; will Mr. Havelka please include this information in his written reply?

MR. J. F. PICKUP: I would like to ask if all the curves referring to light cost refer to single coil lamps and whether coiled-coil lamps are not now available in Czechoslovakia.

MR. HAVELKA (in reply): I agree with Mr. Penny that we should concentrate on achieving the lowest consumption of electrical energy. My formula should, therefore, give the fullest information to the mathematically minded user as to the extent to which he can afford to increase his expenditure on lighting. It serves equally well for special cases as for countries where lamps are scarce.

Our practical observations agree that the lower limits of objective life of the lamp should be about 500 hours and the upper about 2,000 hours. Even within these reasonable limits and with suitable "loading factors" to express the bias towards low energy consumption, the savings achieved in the choice of economical voltage ratings can be interesting.

In reply to Mr. Waldram's criticism of the approach to the problem of maintenance cost, the matter is clearer if we suppose that, e.g., a workshop is lighted by a number of 10,000-lumen lamps soiled so as to emit only 10 per cent. of their original light flux. When the lamps are eventually cleaned, it would be possible to use 1,000-lumen lamps to provide the same working conditions, i.e., the same economic results of the lighting. From that point of view we can say that 90 per cent. of the energy supplied is wasted by dirty fittings, and the consumer pays 10 times the proper cost for his light. Therefore, if the fittings are cleaned regularly, at reasonably short intervals, smaller lamps or fewer lamps could be used.

I agree fully with Mr. Waldram that the uniformity of life of the lamps is of great importance if a group replacement scheme is used. It is another—often neglected—benefit offered by the highly developed lamp industry, that it can supply lamps of uniform quality to the customer.

The observations made by Mr. Stephenson which show lower light losses, even in dirty industrial situations in your country, are surely correct. We use, in many of our factories and industrial centres, brown coal with a large percentage of ash and therefore there is more dirt present in the atmosphere. For that reason the loss of light in our industrial regions is greater than in yours.

The lumen maintenance of the lamp itself is not included in the slope of the depreciation curves, the measured illumination values having been adjusted to what they would be if a new lamp were used all the time. Separate components of the depreciation were also measured, but the results could not be included in the paper.

I would say in reply to Mr. King's question that in our country a supply voltage of 220 A.C. is standard and all the calculations were made with respect to this voltage; this information was unfortunately omitted in the original paper.

In reply to Mr. Pickup, the analysis of light cost is made for single coil lamps; coiled-coil lamps are not at present produced in Czechoslovakia.

Surface Distribution Factors and the Inter-Reflection Method

In a paper of the above title (*Transactions* **20** No. 9. 1955) Mr. R. Croft states that no alternative to the Harrison and Anderson lumen method of interior lighting design was available until 1946 when Moon and Spencer published their inter-reflection method of lighting design.

M. Jean Dourgnon has pointed out that in 1928 (*Revue Generale de l'Electricite*, **23**, 271 (1928)) he published a general method of computing utilisation factors, and showed later (*R.G.E.* **23**, 609) (1928)) that the method was a quite general one for calculating inter-reflections. M. Dourgnon also points out that this general theory had been given by Yamauti in the *Journal of the Optical Society of America* (November 1926) but that at the time he was not aware of this. Buckley (Proceedings C.I.E. 1928) showed that inter-reflections were governed by an integral equation of Fredholm's type, the solutions by Yamauti and Dourgnon being similar to the original Fredholm solution of his equation. M. Dourgnon has compared some of the methods of calculation in *Cahiers du Centre Scientifique et Technique du Batiment* (No. 64, p. 9. 1949) and also for the Commission Internationale de l'Eclairage (Zurich, June 1956) as part of a study intended to devise inter-reflection tables that may have international agreement.

In reply to the points made by M. Dourgnon, Mr. Croft states:—By "no alternative method . . .", I meant no generally accepted alternative method. In M. Dourgnon's excellent earlier papers, although the basic theory is sound, the method was not developed beyond the state of awkward equations to a collection of simple graphical or tabular data which could be used by the practising illuminating engineer with the aid of no more than a little arithmetic; thus it was not comparable with Harrison and Anderson's method and could not in practice be considered as a suitable alternative. Moon and Spencer recognised this defect and stated (*J. Franklin Inst.*, **242**, 112 (1946)) "As a result, the equations are inherently cumbersome; and for routine design, tables or graphs are almost a necessity." This led to their simplified technique and in these circumstances, I feel nothing should be allowed to detract from the credit due to them.

The Lighting of Standard Factories on a Trading Estate

By J. S. McCULLOCH *(Fellow)*

Summary

After the depression in industry in the 1930s the Government passed the Special Areas (Development and Improvement) Act of 1934 and that led to the formation in May, 1936, of a company called the North Eastern Trading Estates Limited, with registered offices on the Team Valley Estate, Gateshead on Tyne. The Company acted as the agent for the Commissioner of Special Areas, to acquire and develop estates to attract light industries to the Area and so secure a better national distribution of industrial activity. There are now 35 estates in the North Eastern Development Area, housing over 300 tenants and giving employment in light industries to over 52,000 people.

In 1945 the Estate Company developed a Standard Factory of which large numbers were built on its estates. A standard lighting installation was developed to meet the requirements of the majority of prospective tenants, who connected various light sources to it. The annual cost of these lighting installations using different light sources is compared, taking into account the annual charges of wiring installation and fittings, replacement charges for lamps and cost of the electrical energy consumed. Some comments are made on the types of fittings used by the tenants.

(1) Historical

On the North East Coast, the words "Small Factories" conjure up a picture of the many Trading Estates sited in Northumberland, Durham and North Yorkshire. Not that there are not many factories, large and small, elsewhere in the Area, but on the Trading Estates are grouped, some in large numbers and some in small, modern, well-designed and well-laid-out factories housing a very wide range of light manufacturing industries.

From the unemployment of the early 1930s arose the first Special Areas (Development and Improvement) Act of 1934. Under this Act a company called the North Eastern Trading Estates Ltd. was formed in May, 1936, as a non-profit-making company to acquire and develop an Estate of 700 acres at Team Valley, Gateshead on Tyne. The Company's primary task was to attract light industries to the Area and away from Greater London and thus, in the words of the Commissioner for Special Areas, "secure a better national distribution of industrial activity, and the Special Areas would benefit by obtaining a share of the diverted development."

This Company differed from older industrial estate companies in many respects. It was established and financed by the Government in a Special Area, and the freehold of the factories belonged to the Company which also built the factories and rented them to the occupiers.

There are now 33 estates in the Area, all owned by the Estate Company, which, since the passing of the Distribution of Industry Act in 1945, now acts as agent of the Board of Trade. The 33 estates contain over 12,000,000 sq. ft. of factory area, housing over 300 tenants and giving employment in light industries to over 52,000 people. The largest factory under one roof is just under 300,000 sq. ft. and the average size is about 30,000 sq. ft.

The author is with R. W. Gregory and Partners. The manuscript of this paper was first received on March 20, 1956, and in revised form on June 29, 1956. The paper was presented at the Society's Summer Meeting held at Harrogate on May 9, 1956.

(2) Standard Factories

At the end of the war in 1945 the Estate Company anticipated a great demand for factory space, so " Standard " Factories were designed to meet the expected requirements of most of the prospective tenants. It was thus possible, at a time of shortage of material, to place bulk orders for building materials.

There were two basic types of Standard Factories, one with clerestory windows and the other with North light roof. There were slight variations within the types, for example, the clerestory factory was built with two different types of roof, steel decking and R.P.M. sheeting, and the North light was built with the ridge running either along the length of the factory or across the width. The floor area of all types was about 24,000 sq. ft., including a two-storey office block. Each Standard Factory was a unit, two could be put together to make a double-sized factory or standard bays could be added at the end to make the factory a little larger than 24,000 sq. ft. Fig. 1 shows typical cross sections of the four different types.

Plans were made to build over 70 Standard Factories, but the capital restrictions of 1947 curtailed the programme and only 52 were actually built.

Advance bulk ordering reduced the time required to complete the factories, but time was also saved by the use of standard building drawings and bills of quantities for all the factories. This saving of time and the bulk ordering of materials helped to reduce the cost.

The Standard Factories, with their slight variations, proved very adaptable to

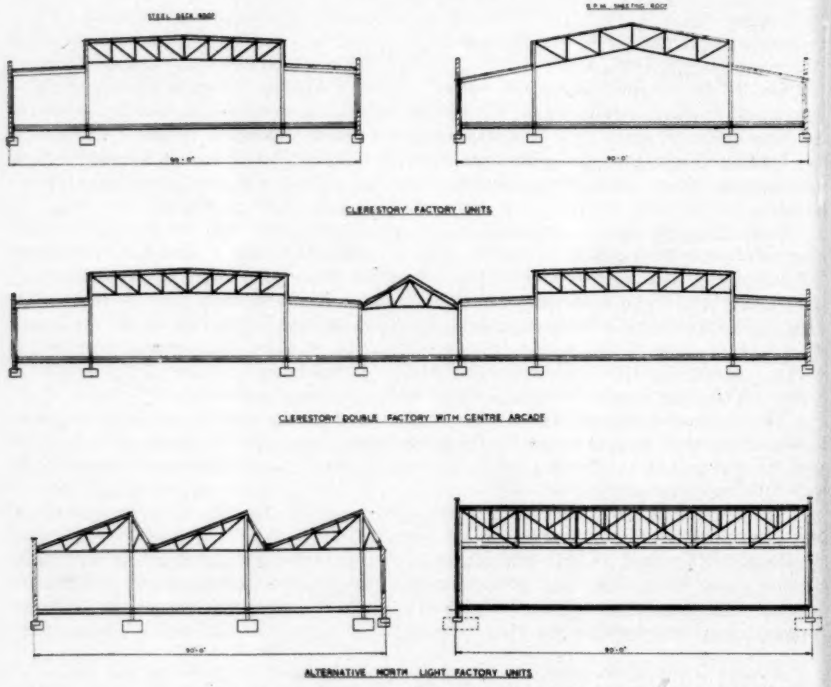

Fig. 1. Typical sections of standard factories.

diverse types of industry and the Estate Company is to be congratulated on the success of what, at the time, was thought to be a very advanced policy fraught with risks.

That the Company was right in anticipating the demand was proved by the fact that all 52 Standard Factories were let before their building was completed.

(3) The Lighting Installation

The Standard Factories were built and let complete with a space-heating installation of the unit heater and radiator low-pressure hot-water type and a lighting installation.

When the Estate Company first started in 1936 it provided in its factories a lighting installation complete with pendant drops and industrial dispersive reflectors in the factory area and simple glass shades in the offices. The average value of general illumination provided at the working plane in the factory area was 6 lm/ft^2 with 200-watt tungsten lamps. It was soon found, however, that tenants had differing ideas on fittings, and furthermore it was realised that it was not the best arrangement for the landlord to be the owner of small removable articles such as lighting fittings. After 1938 the Company provided the lighting wiring only up to the ceiling rose, leaving the tenant to complete the installation.

Experience had shown that tenants' requirements were most economically met by providing installations which gave a general level of illumination over the factory floor, rather than by attempting to design and provide individual installations for each factory. It will be appreciated that the Estate Company, as landlord, does not want its capital spent on special installations which will possibly be of no use to a later tenant.

The Company does not follow this practice rigidly. If, for example, a prospective tenant completes the tenancy negotiations before the factory design has been completed, a special lighting installation, and even a special heating installation, can be provided if the cost is borne by the tenant either as a lump sum payment or by amortisation over the first break period of the tenancy agreement.

When the post-war programme was planned it was realised that a general level of illumination of 6 lm/ft^2 was no longer acceptable, and it was agreed that the new Standard Factories should be provided with an installation allowing much higher values of illumination.

The 80-watt hot cathode fluorescent lamp had come into use during the war and, with its higher luminous efficiency, it seemed that the lighting installation for the Standard Factories should be designed round the new lamp. It was soon realised, however, that this lamp would not meet the requirements of the majority of prospective tenants, many of whom would be new firms anxious to spend what little capital they had available on machinery and material.

Regrettably, the cost of lighting fittings is nearly always looked upon as a necessary evil, particularly by small firms. The new lamp with its control gear and reflectors was much more expensive in first cost than the 200-watt tungsten lamp with an industrial dispersive reflector, which then gave a similar lumen output, and despite its higher efficiency, the annual costs on single shift working were higher. It was, therefore, decided to design an installation which was not especially suited to the new tubular fluorescent lamp but which would be suitable to both it and tungsten lamps. The lighting installation shown in Fig. 2 was finally selected as the one most likely to meet the requirements of the majority of tenants.

The drawing shows the lighting installation in a clerestory type factory but the other types had a similar installation. It contained no "frills," it was strictly utilitarian, but it gave the tenant reasonable flexibility in his production layout. The 10 ft. x 11 ft. 6 in. spacing of the light sources and a maximum of two lighting points per local lighting switch gave control of the lighting over a reasonably small

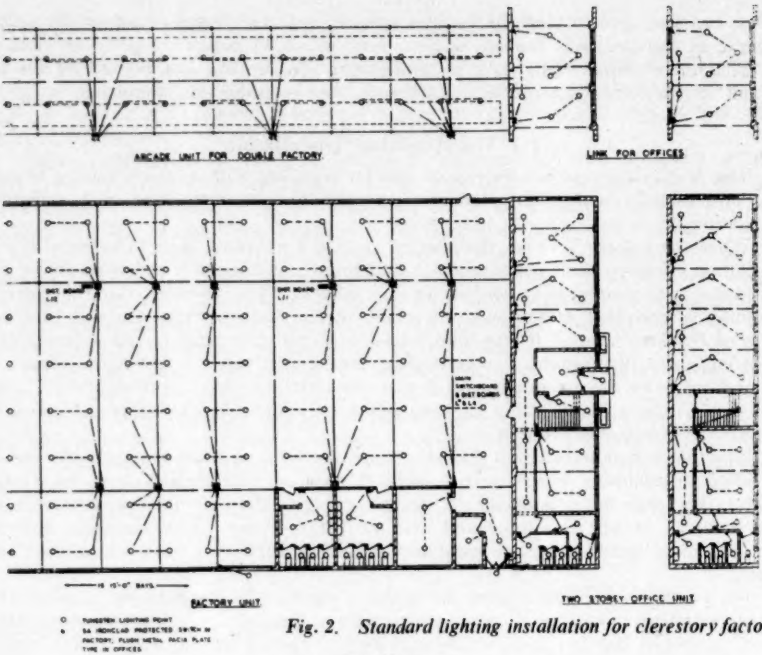

Fig. 2. Standard lighting installation for clerestory factory

Table 1.
Comparison of Illumination Values

Light Source	Type of Fitting	Coefficient of Utilisation	Average Illumination 3 ft. above floor (lm/ft²)
150 W. Tungsten Filament	Industrial Dispersive	.61	8.5
200 W. Tungsten Filament	Industrial Dispersive	.61	12
300 W. Tungsten Filament	Industrial Dispersive	.61	19
80 W. Fluorescent Daylight (1946)	Metal Trough	.61	12
Two 80 W. Fluorescent Daylight (1946)	Metal Trough	.61	21.5
80 W. Fluorescent New Warm White (1956)	Metal Trough	.61	18
Two 80 W. Fluorescent New Warm White (1956)	Metal Trough	.61	32

area and made the installation flexible enough to fit any partitioning required by the tenant.

The cross-sectional areas of the cables in the mains, sub-mains and final sub-circuits and the current rating of all switch-gear and fusegear were designed to carry the load of a 300-watt tungsten lamp at each lighting point.

By using different sized tungsten lamps or installing single or twin 80-watt hot cathode fluorescent lamps, different average values of general illumination could be provided in individual factories to suit the requirements of particular tenants, or varying the light sources in the same factory would give varying values over different areas of the same factory floor—to accommodate fine or rough machining, assembly, packing or stores.

Table 1 shows the average general value of illumination obtained from the standard lighting installation using different light sources. The coefficient of utilisation does not include a maintenance factor.

It will be seen that the tenant had a choice of average values of illumination of 8.5, 12 or 19 lm/ft^2 with tungsten lamps, or 12 or 21.5 lm/ft^2 with the tubular fluorescent lamps available in 1946. Due to the development of the fluorescent lamp since then, the installation in these Standard Factories can now provide average values of up to either 18 or 32 lm/ft^2 using single or twin metal trough reflectors housing the modern 80-watt tubular fluorescent lamps. Further variations can be obtained by using fluorescent lamps of other wattage ratings.

(4) The Wiring Installation

The diagram of connections of the wiring installation provided by the Estate Company as landlord to its tenants, is shown on Fig. 3.

An incoming paper insulated, lead covered service cable of 0.1 sq. in. section was brought into the factory, terminating at an incoming isolator rated at 200 amperes, the isolator forming part of an air insulated unit type switchboard. The Electricity Supply Authority provided the metering equipment and main fuses. The Estate Company provided outgoing switch fuses for its own lighting installation and for its own electrical equipment in the boiler house and the electrical connections for the heating installation. The tenant added busbar units and outgoing switch fuses for his power requirements.

All switch fuses and fused distribution boards were fitted with high rupturing capacity cartridge fuses, and the wiring was single-core vulcanised rubber insulated cables drawn in heavy gauge welded enamelled conduit. Ganged 5-amp. ironclad "protected" surface lighting switches were used in the factory area, and flush types with metal facia plates in the offices. No socket outlets were provided in the factory area, but flush 15-amp. socket outlets were installed in the offices.

(5) Choice of Lighting Installations

Upon the relaxation of control over capital investment after the restrictions of 1947, the availability of materials and the demands for factory space changed, and the need to make provision for advance factory buildings ceased. The Estate Company has, therefore, since 1949, built factories for tenants' particular needs, although it always has to consider that a factory, when completed, must not be so individual in its design that it would not be suitable for other tenants if the existing tenancy terminated.

It has, therefore, been possible to allow more freedom in the design of the lighting installation and, in the planning stage, different types of lighting are now considered in the light of the tenants' requirements.

In some recent factories the advantages of combining the lighting and small power sub-circuit wiring has been recognised. The Estate Company has installed the modern

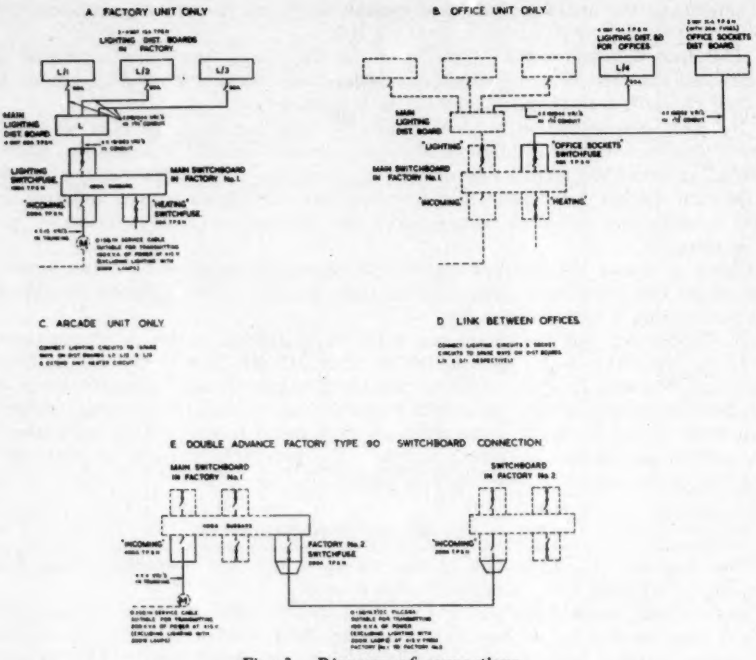

Fig. 3. Diagram of connections.

trunking system where it could be shown to be more suitable for the tenants' requirements.

At the Summer Meeting of this Society held at Southport in 1954, a group of papers was presented on the Economics of Four Industrial Lighting Installations. Each of the four schemes was designed for a particular factory engaged on a particular manufacturing process. After due consideration, each author chose a different light source and each sought to show that his choice of lamp was economically the best for the particular installation with which he was concerned. All the installations were in factories of some considerable size.

It is suggested that it will be useful to consider the economics of a general lighting installation in a small factory using the different light sources now available, and it will be convenient to use as a common basis the Standard Factory described in this paper. Only the economics will be considered, that is, the comparing of the annual costs. No assessment will be made of the distinctive utility values of the differing light sources for specific tasks or for special effects.

Four different lighting installations can be considered in a factory of this size and type, without contravening the well established rules of general lighting design on glare, minimum mounting height and spacing/height ratio. They are :—

(i) 300-watt tungsten lamps in vitreous enamelled industrial dispersive reflectors.
(ii) 80-watt Warm White hot cathode fluorescent lamps in stove enamelled metal troughs suspended from a V.R.I. cable and conduit system.
(iii) The same lamps and special stove enamelled metal troughs suspended from a V.R.I. cable and trunking system, the trunking providing space for small power wiring.

(iv) 240-watt Warm White triple cold cathode fluorescent lamps in stove enamelled metal troughs suspended from a V.R.I. cable and conduit system.

(6) Cost of Electricity

In comparing installations with various light sources of differing efficiencies, the cost of electrical energy consumed has considerable bearing on the economic comparison. All modern electricity tariffs are based on a load factor structure, and one available on the North-East coast for low voltage supplies to industrial premises is :—

(i) A maximum demand charge of £6 6s. per annum for each kilowatt up to 1,500 kw.

(ii) A unit charge of 0.66 pence per kwh. for the first 3,000 kwh. per annum per kw. of M.D., and 0.62 pence per kwh. for all units above 3,000 kwh. per annum per kw. of M.D.

The tariff is subject to a coal adjustment clause by which the unit price is varied by 0.0007 penny for each penny by which the average annual price of Power Station coal is above or below 60s. per ton. With Power Station coal at 76s. 8d. per ton, the two unit charges in the above tariff become 0.8 penny and 0.76 penny per kwh. respectively. Fig. 4 is a curve based on this tariff, showing the average cost per kwh. (unit) plotted against the annual load factor of all the electricity consumed by power and lighting.

It is reasonable to assume that a small engineering factory working a single shift on a five-day week with a two weeks annual shutdown will have an annual load factor of about 17 per cent. The average cost of electricity will therefore be 1.8 pence per kwh. Similarly, for two-shift working the load factor will be about 32 per cent. and the average cost per unit will be 1.35 pence, and for three-shift working the load factor about 55 per cent., and the average cost per unit 1.1 pence. These costs of electricity are used in Figs. 5, 6 and 7 showing the comparison of the annual costs of the different lighting installations in factories working one, two and three shifts.

(7) Hours of Burning

In factories working a single shift the number of hours of burning per annum can vary between 300 and 600 depending on the daylight factor and the nature of the process being carried on in the factory and consequently the average value of general illumination required.

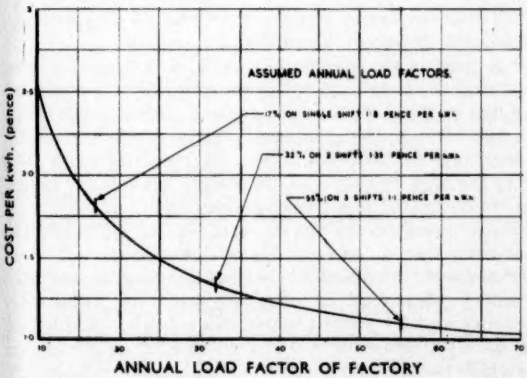
ASSUMED ANNUAL LOAD FACTORS
17% ON SINGLE SHIFT 1·8 PENCE PER kWh
32% ON 2 SHIFTS 1·35 PENCE PER kWh
55% ON 3 SHIFTS 1·1 PENCE PER kWh
COST PER kwh. (pence)
ANNUAL LOAD FACTOR OF FACTORY

Fig. 4. Average cost of electricity per kwh.

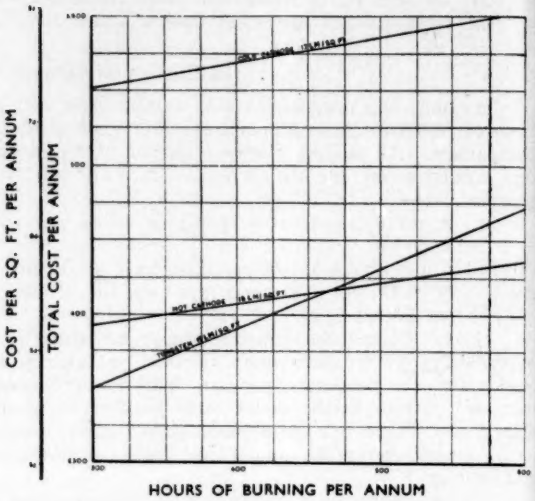

Fig. 5. Single shift working. Cost of electricity 1.8d. per kwh.

For two-shift working, it is estimated that the number of hours of burning per annum can vary between different factories from 1,300 to 1,600 hours, and on three-shift working from 3,000 to 3,600 hours.

The bases of the curves in Figs. 5, 6 and 7 have been drawn to cover these varying annual hours of burning for each of the different shift workings.

(8) Tungsten Filament Lighting

The present-day cost of the lighting installation in the factory area only, shown in Fig. 2, an area of about 18,500 sq. ft., when wired with V.R.I. cables in heavy gauge welded enamelled conduit and fitted with 300-watt tungsten lamps in vitreous enamelled over-lamp reflectors with cool-wiring tops, is about £1,800. Allowing an annual charge of 12½ per cent. to cover interest and depreciation, the annual cost on the capital expended is therefore £225.

The installation consists of 158 300-watt lamps giving a total load of 47.4 kw. and an average value of general illumination of about 19 lm/ft².

In comparatively low buildings such as the Standard Factory, it is suggested that differences between the maintenance costs of the different installations to be considered are so slight that they can be accepted as the same for the purposes of this comparison. All reflectors should be cleaned more often than the interval of time of the life of the lamp with the shortest life, i.e., the tungsten 1,000 hours, and therefore the extra cost of the greater difficulty of cleaning the long reflectors of the longer life tubular lamps is probably balanced against the lower cost of less frequent lamp changing.

The cost of lamp replacement is based on the list price of 7s. 6d. of a general service 300-watt tungsten filament lamp with an average life of 1,000 hours.

The curves of Figs. 5, 6 and 7 show the total annual costs of the tungsten installation installed in the Standard Factory when used on one, two and three shifts with electricity costing 1.8 pence, 1.35 pence and 1.1 pence per unit respectively. Additional ordinates have been drawn on the curves to show the cost of the installations per square foot of factory area. The costs include the annual charge on capital, lamp replacement

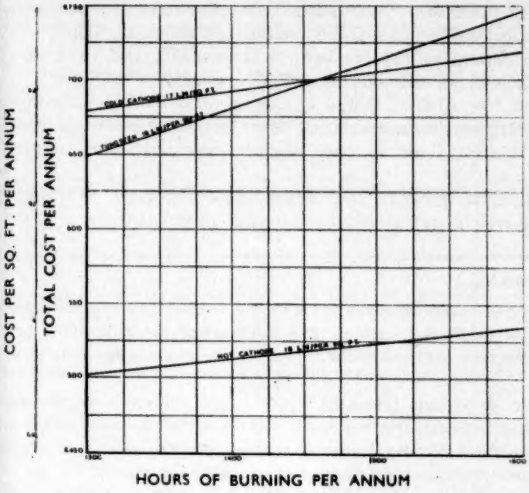

Fig. 6. Two shift working. Cost of electricity 1.35d. per kwh.

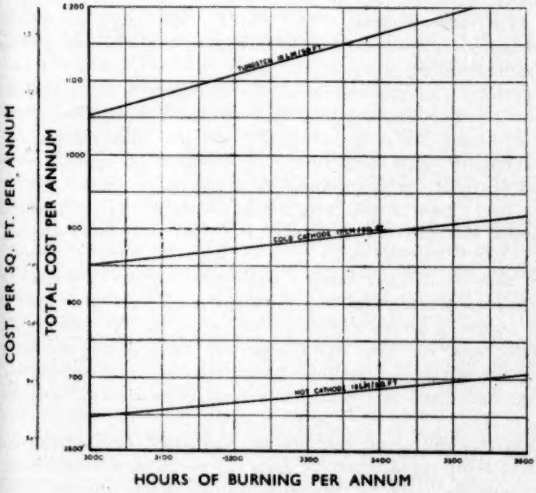

Fig. 7. Three shift working. Cost of electricity 1.1d. per kwh.

costs and cost of energy consumed. They do not include the cost of labour engaged on maintenance, e.g., cleaning reflectors and re-lamping.

(9) Hot Cathode Fluorescent Lighting

(9.1) Hot cathode lamps and conduit installation

Recent tender prices show that the cost of the installation in the factory area only shown on Fig. 2, when fitted with single 80-watt instant start New Warm White

fluorescent lamps in single open-ended stove enamelled removable reflectors and wired with V.R.I. cables in heavy gauge welded enamelled conduit, is about £2,800.

The annual charge on the capital at 12½ per cent. will be £350, and the cost of lamp replacement 17s. per lamp with an average life of 5,000 hours.

The installation consists of 158 80-watt lamps having a total load, with control gear losses, of 15.8 kw., and giving an average value of illumination of about 18 lm/ft² over the lamp life of 5,000 hours. This is only slightly less than the tungsten installation described in Section 8.

These figures have been used to produce the curves shown in Figs. 5, 6 and 7 comparing the costs of the different installations for different shift workings.

(9.2) Hot cathode lamps and trunking

In recent years there have been rapid developments in the manufacture of trunking systems, which house the sub-circuit V.R.I. cables and fluorescent lamp control gear and from which the lighting reflectors and lamps are hung, thus dispensing with much of the conduit system.

Further developments have produced trunking systems of sufficient depth and strength to span the 15-ft. spacing between the Standard Factory roof trusses, and with sufficient room to house, in addition to the lighting wiring, power wiring to small machines. The lamp control gear is also housed in the trunking, generally on trays. The lampholders, or the reflectors with lampholders, are usually attached to the underside of the trunking, though movable along it. The reflectors are hung from easy fixing devices so that the reflectors alone, or in some designs, the reflectors and lampholders, can be removed easily for cleaning.

Fig. 8 shows this type of installation designed for the Standard Factory and giving an average general value of illumination of about 18 lm/ft².

It will be noted that the switching arrangements are quite different from the installation in Fig. 2. One switch for two lamps could be provided by installing pull-cord switches mounted on the trunking, but it is considered that the large number of hanging cords would not be acceptable, and furthermore, this system of lighting with its low energy consumption and flexibility in positioning light sources, does not justify the provision of one switch for every two lamps. Single fluorescent fittings controlled in pairs have been shown in the low part of the factory to provide facilities for partitioning for stores, etc.

The cost of the installation shown in Fig. 8 using a well-known make of trunking spanning the 15 ft. between the roof trusses and fitted with instant start gear, stove enamelled metal reflectors and lamps is about £3,000. This is only £200 more than the conventional conduit system, and for this extra cost the installation provides accommodation in the trunking for wiring to machine tools. In a small engineering works with machine tools closely grouped in rows, this system considerably reduces the costs of power wiring.

As this trunking installation has the same number of lamps as the installation described in Section 9.1 the cost of lamp replacement and energy consumed is the same. The total annual costs will be increased only by the extra annual charge on the £200 increased capital cost, i.e. £25 or just over 0.32 penny per square foot of factory floor.

The total annual costs so closely follow the cost of the installation described in Section 9.1 that they have not been shown on the curves of Figs. 5, 6 and 7.

(10) Cold Cathode Fluorescent Lighting

The development of the cold cathode lamp from its use solely for display and architectural lighting to its use for industrial lighting is comparatively recent. It is a

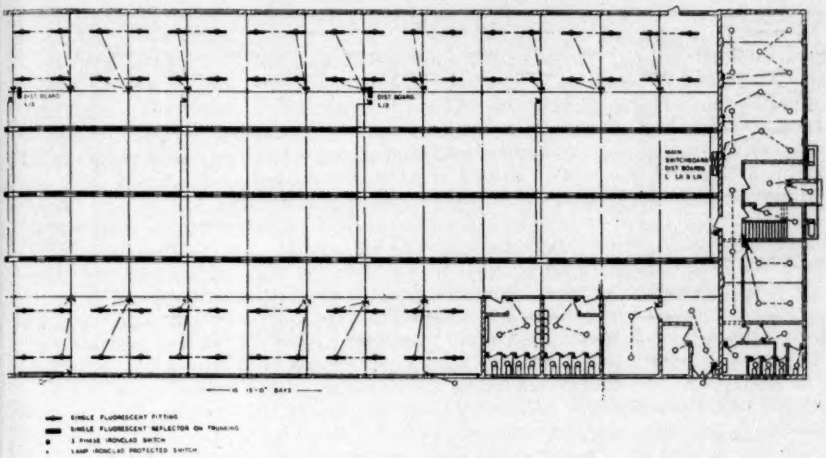

Fig. 8. 80-watt hot cathode fluorescent lighting installation, mounted on trunking in main area.

useful industrial light source when used in its proper place, but some extravagant claims have been made on its behalf. It has an extremely long life and, during the past few years, average periods varying between 10,000 hours and 30,000 hours have been quoted. Recent literature from manufacturers now quotes average lumen output figures over a period of 15,000 hours, and the luminous efficiency over this life is lower than that of the hot cathode lamp. The same literature quotes 7,650 lumens for three New Warm White tubes with an energy consumption with control gear of 240 watts (32 lm/w), as compared with the hot cathode New Warm White lamp with an average lumen output over 5,000 hours of 4,160 (41.6 lm/w).

It is claimed that the long lamp life reduces maintenance costs, but the cost of regular reflector cleaning is by far the largest portion of the cost of maintenance labour, and cleaning has to be done at the same intervals on reflectors housing both hot and cold cathode lamps. Maintenance contractors confirm that if relamping is done at the same time as reflector cleaning, the labour costs are not unduly increased. It is difficult to see how the height of the installation assists the economic case for cold cathode lamps as is claimed. If, as maintenance contractors contend, lamp replacement costs little extra in labour if done when reflector cleaning, the height of the fitting is immaterial.

The value of cold cathode lighting in industry seems to lie in its aesthetic value in large high open factory areas and offices. Very quickly after installation, the odd lamps show their defects, are replaced, and the whole installation then settles down to a long life without further lamp failures. The "hotch-potch" pattern of unlit lamps, often seen on a large hot-cathode installation, is absent.

The cost of this aesthetic advantage should, however, be made clear to the prospective user.

Fig. 9 shows an illustration designed for the Standard Factory, comprising of 80 10-ft.-long cold-cathode industrial stove-enamelled fittings housing three New Warm White 120mA tubes, each fitting having a consumption of 240 watts with its control gear. Because of its comparatively low height the Standard Factory may be regarded by some as not particularly suited to the use of the cold-cathode light source, but the

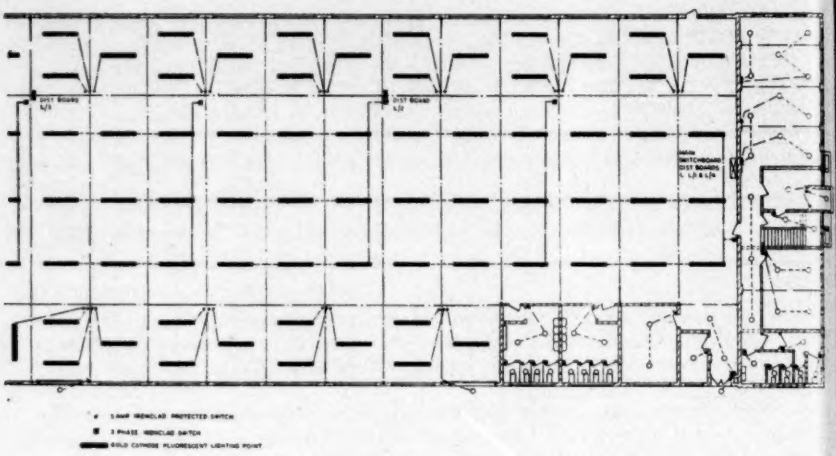

Fig. 9. Cold cathode fluorescent lighting installation.

installation does not contravene any of the accepted rules as regards glare, surface brightness or mounting height.

The cost of the installation shown in Fig. 9, in the factory area only, when wired with V.R.I. cables in conduit, is £4,000. The annual charge on the capital at 12½ per cent. is £500 and the cost of lamp replacement £5 9s. 6d. per three tubes with an average life of 15,000 hours. The total load of the installation is 19.2 kw. and the average value of illumination is about 17 lm/ft^2. These figures have been used to produce the curves shown in Figs. 5, 6 and 7.

(11) Comparison of Annual Costs

In the conditions postulated, the following conclusions are reached, on comparing the annual costs shown graphically in Figs. 5, 6 and 7.

(i) The tungsten lighting installation has the lowest annual charge up to about 475 burning hours per annum on single-shift working, after which the hot-cathode installation is the cheapest. Before the advent of the new higher-efficiency hot-cathode lamps, tungsten installations were cheaper over a longer annual burning hour period.

(ii) With the increasing cost of coal and consequently the increasing cost of electrical energy, and the possibility of still further developments in electric discharge lamp lighting, the use of the tungsten lamp in industry seems likely to diminish still further.

(iii) The discharge lamp is economically supreme in industry where the burning hours are over 500 per annum.

(iv) Although the cold-cathode fluorescent installation has some aesthetic value in industry, it costs over 30 per cent. per annum more than an equivalent lumen-output hot-cathode installation.

(v) As the cost of the trunking installation is only 7 per cent. more than the conventional conduit system, and it provides accommodation for small-power wiring, its use in shops containing rows of machine tools will show a considerable saving in the total cost of power and lighting wiring.

(12) Fittings

A large number of vitreous enamelled industrial dispersive reflectors housing tungsten lamps are used in trading estate factories, mainly by the smaller firms working single shifts. The values of illumination generally provided are round about 10 lm/ft^2. The smaller firms are generally frightened by the cost of higher values of illumination.

However, more and more firms are installing hot cathode installations, particularly large firms opening branch factories on these estates. Values of illumination range from 10 to 30 lm/ft^2, as firms in this category generally accept the I.E.S. Code for the different types of processes.

For hot cathode installations, the standard stove enamelled open-ended metal trough reflectors are the most popular because they are the cheapest. They are often suspended from the conduit system by steel wire and connected to the trading estates wiring installation by tough rubber cable from the ceiling roses. Some are fixed in the normal manner by conduit pendants from the conduit boxes of the wiring installation, and the use of removable reflectors fixed on trunking systems is increasing.

Many firms would like to use vitreous enamelled troughs but their cost is a deterrent. Experience has shown that the open-ended vitreous enamelled variety craze and crack easily when handled by maintenance staff and even the closed-end form is susceptible to damage if dropped when being cleaned. A reflector in which the side panels are removable as flat vitreous enamelled sheets should suffer less from damage during cleaning. The recent introduction of the synthetic resin enamelled reflectors may fill the gap between the comparatively short life of the cheaper stove enamelled reflecting surface and the long life of the more expensive vitreous surface.

Translucent trough reflectors are seldom used in these small factories because of the higher cost. Some of the bigger firms use them in the offices, but the majority use simple batten type of fittings fixed direct on to the ceilings.

Surprisingly, there is little demand for instant start control gear, probably because of the higher cost and the noticeable improvement in the reliability of starter switches in recent years.

Many, if not most, of the tenants' installations suffer from lack of maintenance. Hot cathode lamps are left in service long after their useful life is finished and, of course, dirty reflectors are the rule rather than the exception. Few managements seem to take any positive action on regular cleaning of reflectors.

Finally, the author would like to thank Mr. J. C. Dixon of James Scott and Co. (Electrical Engineers) Ltd. for submitting detail quotations for the four installations described and to his own colleague, Mr. J. Waller, for checking the calculations and assisting with the preparation of the drawings.

Discussion

MR. RICHARD GREEN: One can readily appreciate the fact that the tenant of factory premises will require the lighting and electrical installation to suit his individual requirements. The question of the cost being borne by the tenant has been explained; it was noticeable in the paper that no specific reference was made to I.E.E. regulations and the I.E.S. Code, and I feel that some mention should have been made of them in the paper. One cannot help feeling that such minimum requirements for safety and efficiency should have been brought out most strongly by the ruling body or by legislation at the outset of such a scheme. The author did mention a strict specification; we hear too often these days, however, of cut-throat competition in similar projects where short terms are involved and where it may be considered that the cheapest open tender should be accepted, regardless of these two very points, safety and efficiency. With

my tongue in my cheek, I should be very interested to learn if independent consultants were employed on these schemes. In the paper, we are told that tenants thought the cost of the lighting fittings to be necessary evils; from experience, one wonders about the quality of the electrical installation in such cases. Details of the electrical installations are given rather briefly in the paper, and one feels the author should have devoted a little more space to this section. Why was it considered necessary to have H.R.C. fuse distribution boards specified? Was this a rule not to be broken? There can be two schools of thought on this very subject, for lighting circuits.

The comparisons are interesting, but I doubt whether any fundamental rules can be brought out and the choice can be in one direction only; it is not always advantageous to use trunking and to have, as it were, all the eggs in one basket. I know that certain consultants and electrical engineers are against this practice. Might I add that it looks very easy on a plan, but in practice it is not quite the same thing. But the facts and figures we have seen give food for thought, and I, ladies and gentlemen, shall be very interested in the discussion which follows and which I have had the privilege of opening this afternoon.

MR. C. DYKES-BROWN: I should like to refer in particular to the section of the paper in which consideration is given to the use of cold cathode lighting. The author states that the development of the cold cathode lamp for industrial lighting is comparatively recent, and I should like to remind him that, to my knowledge, a few cold cathode installations were carried out in small factories in 1937. At that time, of course, the hot cathode fluorescent lamp was not available, but it is a fact that cold cathode lighting was not developed quite as recently as some people think.

Next, I find the statement " some extravagant claims have been made on its behalf," but these do not appear to be stated in the paper. I should be interested if the author could elaborate on this.

The comparisons which we have been shown are based on a lamp life of 15,000 hours. No doubt the author's justification for this is a reference he has seen in a publication giving the average lumen output over 15,000 hours, but he is incorrect in assuming that the end of the useful life is after 15,000 hours operation. The life of a cold cathode lamp of reputable make, and running at accepted normal current, is well in excess of 15,000 hours, and I would not be far out to suggest in excess of 25,000 hours. The depreciation in efficiency between 15,000 hours and 25,000 hours is little more than one lumen per watt.

The comparisons made would be on a fairer basis if a life of 25,000 hours were taken and I think we should then see a different state of affairs from those which have just been presented to us.

It may be of interest to recall that one of many cold cathode installations which had been completed as far back as 1937 was on board R.M.S. " Queen Mary " and the first lamp in that particular instance did not fail until after 37,000 hours continuous burning.

I cannot agree that " its value in industry seems to be its aesthetic value in large, high, open factory areas and offices." It is inconceivable that some of the largest industrialists in this country, and indeed some of the Ministries, specify cold cathode lighting for very extensive installations because they like the aesthetic appearance. I can recall many industrial installations, one with 14 miles of cold cathode tubing, another with 18, and one with well over 40 miles in one block of buildings, and all these were carried out after carefully considering the merits of cold cathode lighting for each particular installation, and not because the management did not wish to see dark patches here and there when going round the works.

In summarising my remarks I do not wish to challenge the annual charges shown in the paper; they are probably correct for a life of 15,000 hours, but I do suggest a

further comparison be made for a period of 25,000 hours life. Much as we should all like to see reflectors cleaned regularly, I am sorry to say that this is rarely the case in practice. I suggest, therefore, that in considering maintenance costs the author has stressed too much the fact that lamps will be changed automatically when cleaning takes place at regular intervals. It may be difficult, on grounds of economics alone, to justify the use of cold cathode lighting in the smaller factories, but I cannot accept the author's conclusion that cold cathode lighting is of aesthetic value only, irrespective of the size of the factory; at least that is the inference from the paper.

MR. L. H. HUBBLE: I was going to comment on this paper anyway but I also wish I had the opportunity of replying to the points Mr. Dykes-Brown has just made; it would be a lot of fun. However, I will stick to the rules and say that the paper is exceedingly valuable, as one would expect from Mr. McCulloch. It is factual, and he is a man I know to be meticulous in all his research and calculations in the work he does for his clients, and therefore one does not dispute them, one merely amplifies them a little bit.

He has made some reference to trunking, and I think he could conceivably put the matter a little clearer when advising clients on the question of trunking and the installation costs of trunking. I have known, over some years' and many miles of experience, that conduit and trunking systems break even at about 20 lm/ft^2. It is quite obvious that the more lamps and reflectors you attach to one unit length of trunking the cheaper the installation will be, and if you have two or three hundred feet of trunking and only one reflector assembly on it, it is going to be very expensive. As a general rule, at 20 lm/ft^2 the two systems just about break even.

Mr. McCulloch refers also to the small power wiring which you might put into trunking. Trunking is also an exceedingly useful thing for a number of purposes. It will accommodate visual signals, music while you work, inter-com and, in certain trunkings with small modifications, even the G.P.O. have agreed to have their telephone wires put in. It may not always be so in the case of smaller factories but in large factories it may be very useful to carry the wiring for all these services in your lighting trunking.

I was very glad to see his economic graphs, because one always is accused of having an axe to grind, and I have no axe to grind. It does not matter to me what sort of lighting is used; therefore I can be completely objective. I made a statement some time ago that no one can afford tungsten lighting nowadays, and the total additional capital cost of fluorescent lighting is recovered during the life of the first replacement lamp of a hot cathode installation. I am very glad indeed to see that Mr. McCulloch has confirmed that.

MR. HOWARD LONG: Unfortunately we have a little overlap with the paper that follows, and I will shorten my comments on this one. I think, first of all, the Society is to be congratulated on having consultants and contractors now contributing papers. I am sorry that the subject matter this afternoon has been confined merely to the engineering approach to lighting and not to the lighting approach, because you may get the reflectors right over the machines and that is no help.

The maintenance question is, I think, the greatest factor we have to consider in lighting. It is no good all this other work being done if the equipment gets extremely dirty, which it does. The paper that follows tells us that certain people have their cleaning done regularly, but that is exceptional. Therefore, the question of maintenance is most important, and I am raising it here because it is dealt with in this paper as well. The matter of access to the fittings for relamping is brought out, quite rightly, by Mr. McCulloch, and the only point I would like to suggest is that it is best to keep the dirt out.

Finally, I am sorry Mr. McCulloch has had such unfortunate experience with vitreous enamel, which does not seem to line up with the experience of the majority of people.

MR. B. C. ROBINSON: As one engaged for much of my time on the design of industrial installations, I am interested in the spacing and layout put forward by the author. I note that the unit area per fitting is of the order of 115 sq. ft., and I feel that the author and his partners should be congratulated on the flexibility of the scheme with different intensities available from differing light sources.

I appreciate, of course, that limits are placed on the length of papers and on the number of slides which can be shown, but I think it is a pity that the author gives only diagrams and not a single view of the inside of one of these factories. I am left, therefore, with some points on which I should like enlightenment; I will confine myself to two at the moment: (a) I have just used the trunking system for mounting fluorescent fittings in a textile factory in Yorkshire, and I like it. Mr. McCulloch advocates its use as a means for supplying small machines and machine tools; how are these connected—by conduit, or tough rubber flexible, or armoured flexible cable? (b) Does the design cater for any upward light by using slotted reflectors; is acrylic plastic employed, or is it considered to be too expensive?

On the question of quality of light the author appears to advocate Warm White rather than Daylight. For textile work we prefer the latter. Is Warm White chosen because of the predominance of female labour, or is it even concerned with the colour of the tea, as mentioned this morning?

I find the economics discussed in the paper most interesting, and I am in broad agreement with many of the author's figures; but no account appears to have been taken of replacements for chokes and capacitors—surely a necessity in the best of fluorescent installations. Again he says that "instant start" gear is unpopular; why, then, does he base his calculations on it?

While I agree that it is difficult to make a case for cold-cathode lighting against hot-cathode in general factory work, I have employed it for research laboratories and consider that it may yet become the light of the future.

MR. S. ANDERSON: I do not wish to add to the divergent opinions which have been given on the value of cold-cathode lighting, but it is only fair to underline the scale on which Mr. McCulloch's cost-comparison graphs were drawn. Perhaps those sitting farther from the screen could not see that the lowest horizontal was not the zero line, which would have been well below the bottom margin of the screen. The cost of cold-cathode lighting, therefore, was only 50 per cent. or 60 per cent. more than the cheapest form shown on the left of the graph, not two or three times as costly as it appeared from the relative heights of the ordinates on the screen.

I would like the author to amplify his mention of the value of lighting trunking for carrying the cables for other power and communication services. Some time ago, I had occasion to make inquiries on this point and was surprised and disappointed that it did not appear that users were taking advantage of this feature of lighting trunking. If the author's experience contradicts this, I should be interested to have details.

DR. R. G. HOPKINSON: I have two small questions. I am disappointed with the standard of visual comfort which Mr. McCulloch describes in his paper. I would like to ask, could we not aim for a rather higher standard of visual comfort by getting some upward light, using inter-reflected light, and trying to reduce the level of glare discomfort? This need not necessarily mean more expensive lighting.

My second question is this; the calculations of lighting economy given in the

paper are based on the conventional figure of 1,000 hours for the life of the filament lamp. Could I ask if this life is, in actual fact, interfered with by voltage fluctuations?

(*Communicated*). My second question was prompted by the fact that we have measured the actual life of tungsten filament lamps, taking advantage of the facilities provided by the Abbots Langley Experimental Housing Estate, where 72 lamps lighting staircases, entrance halls, and bicycle sheds in three blocks of flats, together with 29 street lamps, have been checked for actual life. The burning life of about 450 lamps has been determined and their mean life was found to be much shorter than that normally assumed. The wide spread of individual lives about this mean suggested that group replacement of lamps could not be recommended. None of the information collected in this study is in any way at variance with the lamp manufacturers' own published data on the relation between lamp life and other factors, for example voltage applied at the lamp terminals. Nevertheless the effect in practice is that the user finds that his lamps do not achieve the published life of 1,000 hours. Calculations of lighting economy, for example the relative cost of fluorescent and filament lighting, must take such effects into account. It would be interesting to know if the author has found any comparable effects in his wide experience.

MR. A. KALLENBACH: As a lighting engineer practising in South Africa, I have been very interested for a long time in the cold versus the hot cathode. I too have found that, for purely economic reasons, hot cathode lamps usually have a definite advantage. I would like one of the previous speakers in the discussion to explain why where there is a life of 25,000 hours burning, he only gets a depreciation of one per cent. in the lumens per watt figure. Secondly, I would like to have Mr. McCulloch explain to what extent miniature circuit breakers of the American pattern are used for the protection of circuits instead of H.R.C. fuses. We use H.R.C. fuses considerably, but very often in conjunction with M.O.B.s as miniature circuit breakers, instead of, or as well as, fuses.

MR. MCCULLOCH (in reply): In reply to Mr. Green, all the electrical installations were designed by independent firms of consulting engineers and consequently the I.E.E. Regulations are rigidly observed. In general, the tenant is responsible for the lamps and lighting fittings and consequently the I.E.S. Code does not enter into the specification. I apologise for the briefness of the description of the electrical installation, but the first draft was criticised because too much space was taken by the wiring installation. Regretfully, the wiring installation is often not of great interest to the lighting engineer.

H.R.C. fuses have been specified in all factories, mainly because the fault current available on the system, particularly at those factories near the Estate sub-station, is fairly high. Another advantage is that pseudo-electricians fit over-rated fuse wires in H.R.C. fuse holders only once!

I agree that it is not always advantageous to use trunking but I have not had any troubles using it to house small power wiring and lighting circuits. I have not yet added communication circuit wires as mentioned by Mr. Hubble because of my fear of interference.

Mr. Dykes-Brown corrects my historical reference and my mistake must be due to a surprising lack of publicity. The extravagant claims to which I refer in the paper were made some years ago when 30,000 hours was claimed as the average efficient lamp life of cold cathode tubes. I used the figure of 15,000 hours as this is now the generally published one. Mr. Dykes-Brown's statement that the depreciation in efficiency between 15,000 and 25,000 hours is little more than one lumen per watt is surprising. If this statement can be substantiated by published tests, I agree that the curves used in the papers should be amended. The comparisons made in the paper must be based on published figures and that is why I have used 15,000 hours. Using

my figures, I have examined the economics of three or four large cold cathode installations and I have been unable to justify any of them on economic grounds alone.

I suggest to Mr. Dykes-Brown that in comparing different types of installations it is not logical to assume that because one type of lamp has a longer life than another it is therefore not cleaned at the same intervals.

I agree with Mr. Hubble that the cost of conduit and trunking systems is about the same at a value of illumination of about 20 lm/ft^2. This does not take into account the added advantage of accommodation for small power wiring. In the paper I did not confirm that "no one can afford tungsten lighting in our days"; I said that tungsten lighting is still cheaper under about 450 burning hours per annum. It is, however, not necessarily so good a source of illumination.

I am sorry Mr. Long felt that the scope of the paper was limited. It was limited by the number of words I was allowed.

In reply to Mr. Robinson, I recommend clients to use conduit from the trunking to the machine, but care must be taken with the earthing of the conduit to the trunking wall. When I can persuade a client to spend the extra money, I prefer to run an earth wire down the trunking when used for power circuits and not rely on the copper connectors which are provided. In these conditions a separate earth wire can be run down the conduit to the machine. If a separate earth wire is not provided one must rely on the male and female bush and test thoroughly to ensure earth continuity. Slotted reflectors are not used generally, mainly because of the layman's objection to "light being wasted on the ceiling." In these modern buildings we very seldom get a tunnel effect from solid reflectors with values of illumination of about 15/20 lm/ft^2 on the working plane. Plastic reflectors are considered too expensive for use in factories, although they are used in adjacent drawing offices.

I prefer the use of the new Warm White lamp, as it is slightly higher in efficiency than the Daylight lamp and because it is more acceptable to female labour. The Daylight lamp is considered by many to be too cold looking.

I used instant-start gear in my comparisons because it is the most expensive and therefore it disarms criticism which might have arisen if I had used the cheaper switch start gear. I am pleased to see that Mr. Robinson agrees with me that it is difficult to make a case for cold cathode lighting in general factory work.

I thank Mr. Anderson for his comments regarding the appearance of the curves. In the published version of the paper I have attempted to correct this.

I agree with Dr. Hopkinson that we suffer at the present time from installations with too much evenness of illumination. We do not take into account sufficiently the varying brightness of walls. However, I find it exceedingly difficult to get industrialists interested in this subject. Dr. Hopkinson's information on tests carried out on the life of lamps in domestic use is most interesting. I have found, in general, that the life of one thousand hours for a tungsten lamp is reasonably correct. On the occasions when I have received complaints, the cause can generally be traced to violent voltage fluctuations caused in the factory itself. I have never been able to substantiate the complaints of clients of voltage variation from the system causing premature lamp failures.

Mr. Kallenbach's contribution is most interesting and valuable, and I am glad to have his agreement to my views on cold cathode lighting in factories. I would like to substitute miniature circuit breakers for H.R.C. fuses. They enable the designer to rate the protective devices to suit the circuits they are protecting and know that they are there for good. No one can increase the load on a circuit, increase the fuse rating and then hope for the best. Unfortunately the short circuit rating of the miniature circuit breakers available in this country limits their use considerably. Furthermore, at the 500-V. range they are more expensive than H.R.C. fuses.

Additions to the List of Members

The following applicants have been duly elected by the Council to membership in the Society and their names have been added to the list of members:—

SUSTAINING MEMBERS:—

The Cinematograph Exhibitors' Association of Great Britain and Ireland
164, Shaftesbury Avenue, London, W.C.2. *Representative*: L. Knopp.

The Merchant Adventurers, Ltd.
43, Portland Road, W.11. *Representative*: W. Boissevain.

CORPORATE MEMBERS:—

Evans, J. H. T. ..... 50, Fordrough Lane, Bordesley Green, BIRMINGHAM 9.
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